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Multi-attribute Selection of Public Buildings Retrofits Strategy

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Abstract

This paper discuss problem of retrofitting strategy selection. The aim is to determine in which way is rationally to update public buildings. Nine feasible alternatives of buildings retrofitting scenarios were developed. The essence of these scenarios is number of stages and time of retrofitting works. A set of five key attributes, which adequately describes the alternatives, was determined and SWARA method was used to determine weights of attributes. Multi-attribute optimization problem is determined and solved. Three different multi-attribute decision making methods (SAW, TOPSIS and COPRAS) were applied to assess and rank alternatives. A small kindergarten in Semeliskes (Lithuania) was selected as a case study. It is determined that most appropriate way for retrofitting of small public buildings is a one-stage with the greatest available number of workers.

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Keywords: multi-attribute; MADM; public buildings; retrofit; strategy.

1. Introduction

Every human society is an enterprise of world-building. Building thermal insulation and HVAC systems are the historical problem of survival, comfort and efficiency. Meanings of comfort have changed dramatically over the last century, with considerable implications for indoor environmental management and energy demand. The HVAC efficiency is increasingly upping with codes and certification standards. Today's systems are giving way to modifications and new innovations to make the grade in low-load homes. The technologies of heating and cooling make heavy demands of the world's energy resources. Builders, scientists, politicians are looking for modern ways for delivering indoor comfort and energy efficiency.

In most cases the retrofit works are carrying out on existing and working public buildings. The attention should be paid on to employees and visitors discomfort due to retrofitting process. There could to be developed a lot of buildings retrofit alternative scenarios. Scenarios are describing by a set of meaningful attributes. Each attribute from different alternative has different value of performance. Aim of the investigation is to select the public building's retrofitting strategy: to divide construction works into a number of stages or not, and what forces (labor) should to be involved to the construction works.

Investigations on building retrofit are a topically presented in world-wide scientific researches. Buildings consume about 40 % of the total energy (European Union member data). It was found that the old building energy consumption for heating exceeds even 150-200 kWh/m^2 per year, the new construction of buildings ranging 55-60 kWh/m^2 per year, while passive

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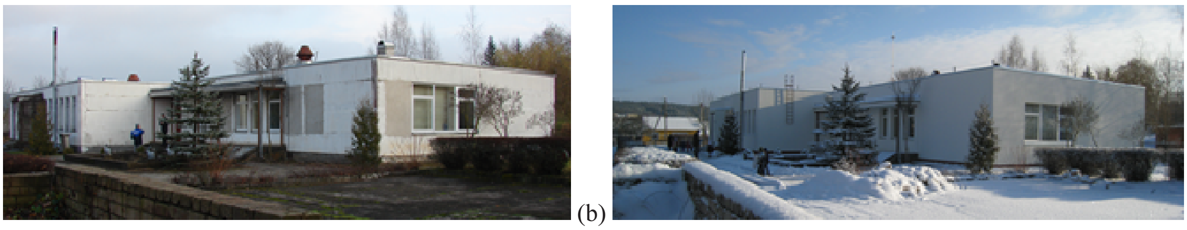
buildings shall not exceed 15 kWh/m^2 per year [1]. In most of scientific researches is pointed that retrofitting of buildings, environmental protection, equitable decision-making and construction quality are interrelated issues and should to be solved as complex problem.

Scientists Juan *et al.* [2] pointed out that during the long life cycle period of housing; most residents are undoubtedly faced with refurbishment requirements. However, it is not easy to make assessment and refurbishment related decisions due to the lack of knowledge and experience. Genetic algorithm – based on-line decision support system to help residents conduct the housing condition assessment and offer optimal refurbishment actions considering the trade-off between cost and quality is presented. Asadi *et al.* [3] determined that one of the best opportunities to improve energy efficiency of the buildings would be during building retrofit. One of the key steps in building retrofit is the selection of retrofit actions among a large number of possibilities. The problem is in fact a multi-attribute optimization problem, characterized by the existence of multiple and competing attributes, a set of feasible solutions that are not predefined but are implicitly defined by a set of parameters and a set of constraints that should be taken into account to reach the best possible solution. Rysanek and Choudhary [4] determined that decomposing holistic and black-box building energy models into discrete components can increase the computational efficiency of large-scale retrofit analysis. The entire framework presents an integrated modeling procedure for the simulation and optimization of retrofit decisions including cost-benefit analysis. Potential decisions can range from the installation of demand-side measures to the replacement of energy supply systems and combinations there within. Konstantinou and Knaack [5] discussed an approach to the designing of refurbishment projects, as a way to energy-efficiently upgrade the residential stock, and pointed out that the design phase of retrofit projects is often problematic. The decisions taken in the early stages of the design determine the final result; however, the assessment of the environmental performance only happens at the end of the design process. Xing *et al.* [6] stated that buildings account for almost half of energy consumptions in European countries and energy demand in building continues to grow worldwide. They categorized a range of technologies for building refurbishment in a sequential manner. A hierarchical process with embedded techniques (insulations, energy efficient equipment and micro-generation) is presented as a pathway towards zero carbon building refurbishment. Golić *et al.* [7] offers various possibilities for achieving higher energy efficiency. As 20 % of total energy consumption in construction sector is used for water heating, it follows that 8 % of total energy in Europe is consumed for water heating purposes. Solar water heating systems are a suitable technology for renewable energy source exploitation to be applied. Ma *et al.* [8] stated that retrofitting of existing buildings offers significant opportunities for reducing global energy consumption and greenhouse gas emissions. Although there are a wide range of retrofit technologies readily available, methods to identify the most cost-effective retrofit measures for particular projects is still a major technical challenge. A systematic approach to proper selection and identification of the best retrofit options for existing buildings and key issues that are involved in building retrofit investment decisions are presented. Brown *et al.* [9] presented a method for assessing renovation packages drawn up with the goal of increasing energy efficiency. The method includes calculation of bought energy demand, life-cycle cost analysis and assessment of the building according to the Swedish environmental rating tool. In this way the methodology assesses economic, indoor environmental quality and environmental aspects.

2. The object under investigation

As a key study's object was selected small kindergarten in Semeliskes (Elektrenai municipality) from Lithuania (see Fig. 1). The kindergarten in Semeliskes is a one-story reinforced concrete frame building. Building total floor area is 478.60 m^2. It was built in 1980. A local diesel fuel boiler-room was constructed under part of building. 240 mm thick porous concrete slabs were used as external walls of the building, and 200 mm thick reinforced concrete blocks as the plinth. The interior and exterior sides of walls were plastered and painted. The building in 2011 was retrofitted. 120 mm thick mineral wool panels were used for thermal insulation of external walls and 100 mm thick extruded polystyrene panels for plinth. 140 mm thick extruded polystyrene panels with 20 mm thick mineral wool panels were used for thermal insulation of roof. Old windows and doors were also changed during retrofit [10].



(a) (b)

Fig. 1. Kindergarten in Semeliskes before (a) and after (b) renovation

3. Case study

There were generated 9 feasible alternatives of retrofitting scenarios. They are generated in such manner: the retrofitting process is broken down into a number of stages, and selection among alternatives is made by employing different number of employees (4, 8 or 12 for construction work carrying out at different speed), see Table 1.

Description of construction stages is given below.

One-stage retrofitting process. The building is upgrading in a single step: replacement of windows, exterior and vestibule doors, roof repairing, installment of ground level floors thermal insulation, exterior walls and basement thermal insulation, updating of heating, ventilation and electric lighting systems. The works are carrying out during the summer season. Retrofitting process can interfere with body's activities due to the large amount of performed construction work at the same time.

Two-stages retrofitting process. The building is upgrading in two stages. At the first stage are replaced windows, exterior and vestibule doors, repaired roof, installed thermal insulation of exterior walls and basement. The second stage includes installment of ground level floors thermal insulation, updating of heating, ventilation and electric lighting systems. Works are carrying out during the summer season (summer holidays). There is one year break between the first and the second stages. There presents a risk (depends on the number of workers) that not all works will be carried out in time and in thus construction works can interfere with body's activities.

Three-stages retrofitting process. The first stage includes replacing of windows, exterior and vestibule doors. The second stage consists of thermal insulation and repairing the roof, exterior walls and basement of the building. The third stage includes installment of ground level floors thermal insulation, updating of heating, ventilation and electric lighting systems. Two one year breaks are making among three stages. The works are carrying out in the summer holidays. In this case the impact of construction works on the institution activities is the least.

Table 1. Initial decision-making (performance) matrix

Alternatives			Attributes				
No.	Stages	Workers	Price with VAT, [€]	Duration of works, [m. d.]	Renovation payback time, [y]	Energy savings through ten years, [MWh]	People's satisfaction, [scores]
1	I	4	130950	200	21.86	365.60	6.66
2	I	8	130950	130	21.86	365.60	11.38
3	I	12	130950	80	21.86	365.60	12.89
4	II	4	137900	230	22.60	352.44	7.46
5	II	8	137900	160	22.60	352.44	12.18
6	II	12	137900	110	22.60	352.44	13.69
7	III	4	141500	245	23.18	318.87	8.27
8	III	8	141500	175	23.18	318.87	12.98
9	III	12	141500	125	23.18	318.87	14.49
Optimality direction			min.	min.	min.	max.	max.
Weight of attribute			0.37	0.12	0.36	0.10	0.05

Description of problems attributes. State agencies usually use only one attribute in their procurement – the lowest price. It does not properly reflect the true economic benefits of touch as well as other important aspects of the retrofitting. The authors selected five key indicators to assess the economic benefits of the renovation and impact of construction works process on staff and visitors.

Price with VAT, [€]. A price of construction works varies depending on the amount of construction work, the current price level in the country (wages, materials and machines), the competitive advantages of contractors, construction time and number of construction stages, which are investigated in this article. Increasing number of construction process's stages raises construction costs. Construction costs increases due to higher construction overheads i.e. must to bring additional domestic and export facilities and bio-toilets for workers, in addition to install and dismantle the temporary construction fence, prepare for the execution of construction works and so on.

Duration of works, [man days]. Time of construction works depends on the amount of works (man-hours) and the number of workers on construction site. This article deals with alternatives (working 4, 8 or 12 workers in a given object – kindergarten in Semeliskes). The construction work must be performed following the requirements of construction technology, which prevents certain works to be carried out as quickly as we would like, for example, after facade mineral plastered, painting can be done only after 21 days (due to chemical processes occurring in mineral plaster).

Renovation payback time, [years]. Payback period of retrofitting is calculated on the basis of the investment required for the construction works and the energy savings, which are the subject to certain construction works (for example, replacement of windows). Calculations of payback time, in this particular case, shall be based on the calorific value of diesel fuel, boiler efficiency, price raises of no-excise duty diesel fuels and on the laboratory studies in the kindergarten in Semeliskes performed by authors of the article. The laboratory studies show real energy savings of certain constructional solutions of retrofitting [10].

Energy savings through ten years, [MWh]. Energy savings over ten years determines the expected economic benefits return on investment. The count rate for a longer period of time is not recommended, because there is a large uncertainty on the energy price variation of the inflation change, energy resources price forecast, and so on. This uncertainty can to be partially reduced if energy savings are determining using amount of energy in [MWh] instead money [€].

People's satisfaction, [scores]. People's satisfaction is calculated based on questioning members of interest groups (building employees and visitors) and data processing Ranking method. 25 stakeholders were involved into survey. 9 points were awarded to the best alternative and 1 point was given to the worst alternative. The survey data were processed by Ranking method and final scores multiplied by 100 %. It is necessary to examine stakeholder opinion overlapping degree (value of concordance coefficient was compared with the value from the table of chi-squared distribution). The determined values of calculation can be used for further calculation when there are sufficiently consistent points of view of respondents.

One of the most important aspects of multi-attribute decision-making is determining of attribute weights. For this reason in this research authors used SWARA (step-wise weight assessment ratio analysis) method [11].

4. Problem solution by applying SAW, TOPSIS and COPRAS methods

Lot of famous researches pointed that for multi-attribute decision-making problems solution several methods should to be used. Reason of this is that in some cases different ranking of alternatives results could to be obtained when different multi-attribute decision-making methods are used. The initial decision-making matrix is presented in Table 1. The problem was solved by applying three different multi-attribute decision-making methods: simple additive weighting (SAW), technique for order preference by similarity to ideal solution (TOPSIS) and complex proportional assessment (COPRAS). The above mentioned methods are methods of multiple attribute utility theory (MAUT) [12].

4.1. SAW method

Based on the SAW method, a weighted sum for each alternative can be obtained simply by multiplying the score function for each attribute by the importance weight assigned to the attribute and then summing these products over all attribute. If one denotes the weighted sum of the score functions as the suitability function, it can be used to determine the degree to which an alternative satisfies the decision-maker's requirements [13]. The SAW procedure consists of following steps:

- Establishing a performance matrix.
- Normalizing the decision-making matrix.
- Calculating the weighted normalized decision-making matrix.
- Summing each alternative weighted normalized decision-making matrix different attributes.
- Determining the ranks of the alternatives [14].

4.2. TOPSIS method

TOPSIS method maximizes the benefit attributes and minimizes the cost attributes, whereas the negative ideal solution maximizes the cost attributes and minimizes the benefit attributes. The best alternative is the one, which is closest to the ideal solution and farthest from the negative ideal solution [15]. The TOPSIS procedure consists of the following steps:

- Establishing a performance matrix.
- Normalizing the decision-making matrix.
- Calculating the weighted normalized decision-making matrix.
- Determining the positive ideal and negative ideal solutions.
- Calculating the separation measures.
- Calculating the relative closeness to the ideal solution.
- Determining the ranks of the alternatives [16].

4.3. COPRAS method

The multi-attribute decision-making method COPRAS was first announced in1994. This method assumes direct and proportional dependence of the significance and utility degree of investigated versions on a system of attributes adequately describing the alternatives and on values and weights of the attributes. Determination of significance, the priority order and utility degree of the alternatives is carried of the following steps:

- Establishing a performance matrix.
- Calculating the weighted normalized decision-making matrix.
- Calculating the sums of weighted normalized indices describing the alternatives. The alternatives are described by positive (maximizing) attributes and negative (minimizing) attributes.
- Determining the significances of the compared alternatives describing the advantages and disadvantages of the alternatives.
- Calculating the utility degree of alternatives. The degree of alternative utility is determined by comparing each analyzed alternative with the most efficient one.
- Determining the ranks of the alternatives [17-19].

Weighted normalized decision-making matrixes are presented in Tables 2-3. Final ranking of alternatives is presented in Table 3.

Table 2. Weighted normalized decision-making matrix (SAW and TOPSIS methods)

SAW method						TOPSIS method					
Alternative No.	Attribute No.					Alternative No.	Attribute No.				
	1	2	3	4	5		1	2	3	4	5
1	0.370	0.048	0.360	0.100	0.023	1	0.118	0.047	0.116	0.035	0.010
2	0.370	0.074	0.360	0.100	0.039	2	0.118	0.031	0.116	0.035	0.017
3	0.370	0.120	0.360	0.100	0.044	3	0.118	0.019	0.116	0.035	0.019
4	0.351	0.042	0.348	0.096	0.026	4	0.124	0.054	0.120	0.034	0.011
5	0.351	0.060	0.348	0.096	0.042	5	0.124	0.038	0.120	0.034	0.018
6	0.351	0.087	0.348	0.096	0.047	6	0.124	0.026	0.120	0.034	0.020
7	0.342	0.039	0.339	0.087	0.029	7	0.128	0.058	0.123	0.031	0.012
8	0.342	0.055	0.339	0.087	0.045	8	0.128	0.041	0.123	0.031	0.019
9	0.342	0.077	0.339	0.087	0.050	9	0.128	0.029	0.123	0.031	0.021

Table 3. Weighted normalized decision-making matrix (COPRAS method) and ranking results by SAW, TOPSIS, COPRAS and Average methods

COPRAS method						Aggregated rank of alternative	Methods results (rank score)			
Alternative No.	Attribute No.						SAW	TOPSIS	COPRAS	Average
	1	2	3	4	5					
1	0.039	0.016	0.039	0.012	0.003	**1**	**3 (0.994)**	**3 (0.947)**	**3 (0.123)**	**3 (1.00)**
2	0.039	0.011	0.039	0.012	0.006	**2**	**2 (0.943)**	**6 (0.765)**	**2 (0.117)**	**2 (2.33)**
3	0.039	0.007	0.039	0.012	0.006	**3**	**6 (0.930)**	**2 (0.709)**	**6 (0.116)**	**6 (2.67)**
4	0.041	0.019	0.040	0.011	0.004	4	1 (0.901)	9 (0.649)	9 (0.112)	9 (4.67)
5	0.041	0.013	0.040	0.011	0.006	5	5 (0.898)	5 (0.520)	5 (0.111)	5 (5.00)
6	0.041	0.009	0.040	0.011	0.007	6	9 (0.896)	8 (0.423)	1 (0.109)	1 (5.67)
7	0.043	0.020	0.041	0.010	0.004	7	8 (0.869)	1 (0.351)	8 (0.107)	8 (6.67)
8	0.043	0.014	0.041	0.010	0.006	8	4 (0.863)	4 (0.151)	4 (0.103)	4 (8.00)
9	0.043	0.010	0.041	0.010	0.007	9	7 (0.837)	7 (0.053)	7 (0.100)	7 (9.00)

Different ranks are determined by applying different methods. The Average methodology could to be applied to determine final ranking of alternatives (see Table 3). Borda [20] or Copeland [21] methods could to be applied also (in case when a different multi-attribute decision-making methods ranks alternatives without match).

5. Conclusions

The retrofitting problems are multi-attribute decision-making problems. Economic benefits, duration of the construction works, discomfort of building's employees and visitors (people's satisfaction attribute) should to be taken into account simultaneously. Different multi-attribute methods may award different ranks to the same alternatives. For this reason, it is recommended to perform calculations by applying several different methods and to compare results. The Average methodology, Borda, Copeland or other methods could to be applied in case when a different multi-attribute methods ranks alternatives without match.

The case study with 9 different feasible alternatives and 5 attributes shows that the best retrofitting strategy for small public buildings is to carry out construction work on the same stage with the greatest possible number of workers (one-stage retrofitting process). In this case, the maximum economic benefit while building employees and visitors experience the least discomfort due to ongoing construction work. The construction of a high speed must to follow and conform to the requirements of construction technology. There is an increased risk of derogation from these important requirements.

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